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The third instance is the maturing of the cerebellum, represented by the completion of the Purkinje cells and the disappearance of the external granule layer. In the rat these events occur between birth and 20 days of age, Addison '11. Like events occur in the human cerebellum and are completed in man at nearly the equivalent age. When the cerebellum has so far matured, locomotor control is attained in both forms, and thus this series of histological adjustments and locomotor control are accomplished at nearly equivalent ages in both the rat and man.

Finally, Dr. Sugita ('17) has just completed a study of the growth in thickness of the cerebral cortex of the rat, and the graph A in chart 3 shows that the mature thickness is nearly attained at the age of 20 days. There are at present no systematic studies on this point for man, but two incidental observations, entered as heavy dots, agree with the inference that at 15 months, the equivalent age, a like degree of completeness is reached by the human cerebral cortex, and therefore that only slight growth in the thickness of the human cortex is to be expected after this age.

There are therefore five prime events in the growth history of the nervous system of the rat, namely: (1) increase in total weight; (2) decrease in the percentage of water; (3) accumulation of myelin; (4) maturing of the cerebellum; (5) the attainment of the mature thickness of the cerebral cortex, all of which takes place at ages equivalent, or nearly equivalent, to those at which they occur in man.

It appears then that by the use of equivalent ages we have a satisfactory method for making a cross reference between the rat and man, and because the growth changes are similar in both forms, the rat may be used for further studies on the growth of the nervous system with the assurance that the results so obtained can be carried over to man.

Addison, William H. F., *Wistar Inst., Philadelphia, J. Comp. Neur.*, **21**, 1911 (459-481).  
Donaldson, H. H., *Ibid.*, **26**, (1916), (443-451); these PROCEEDINGS, **2**, 1916, (350-356).  
Sugita, Naoki, *J. Comp. Neur.*, **28**, 1917, (511-591).

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## VARIATION AND HEREDITY DURING THE VEGETATIVE REPRODUCTION OF *ARCELLA DENTATA*

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The conclusions of several investigators, that the genotype is constant in organisms that are multiplying by fission, have recently been put in question by the work of Middleton<sup>1</sup> (1915) on *Stylonychia* and by Jennings<sup>2</sup> (1916) on *Diffugia*. Middleton obtained two lines of *Stylonychia* from a single specimen

that differed constantly and markedly in their fission rate. Jennings has shown that the descendants of a single specimen of *Diffugia* may be separated into a number of diverse lines that differ from one another in their heritable characteristics. The work herein described is part of an investigation that is being made of the species problem in the genus *Arcella* and the principal problem attacked is: Can heritably diverse lines with respect to spine number and diameter of shell be distinguished among the descendants of a single specimen of *Arcella dentata* produced by simple fission?

*Arcella dentata* (fig. 1) is a microscopic protozoon belonging to the lowest class, the Rhizopoda. It is as simple as any animal organism it is possible to

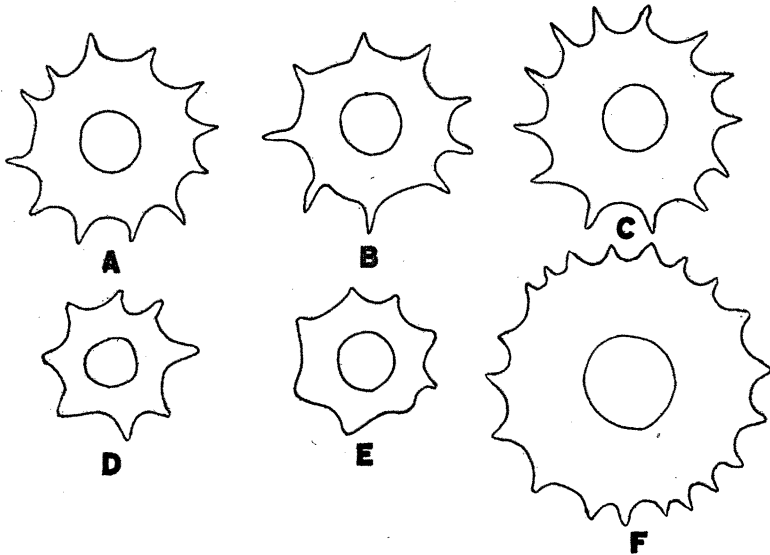


FIG. 1. OUTLINE DRAWINGS OF SPECIMENS OF *ARCELLA DENTATA* BELONGING TO FAMILY NO. 58.  $\times 207$

A, The progenitor of the entire family; B, a typical member of the low line E; C, a typical member of the high line A; D, the small progenitor of the line EM; E, a small specimen from the line ED; F, the largest specimen from the line ED.

obtain that has measurable characteristics. It varies in diameter from 73 microns to 150 microns and in spine number from 7 to 20. It multiplies vegetatively and rapidly and the characteristics of the shell are not modified by growth or by the environment, and are heritable but variable. In all, 6474 specimens were studied. Of these 171 were collected from a pond on the campus of the Johns Hopkins University at Homewood, Baltimore; 746 were reared from 70 of these specimens; and 5557 were obtained from the single specimen numbered 58. The number of generations represented by the progeny in family 58 was 69 and the average interval between generations was two and one-half days.

One hundred 'wild' specimens were first selected at random from a large number taken from the pond. These varied in spine number from 7 to 13, and in diameter from 23 to 33 units (each unit being 4.3 microns). A marked correlation ( $0.325 \pm 0.060$ ) was found between the spine number and diameter of these specimens.

Small families were then reared from 70 'wild' specimens selected so as to include large, small, and medium sized organisms. Seven hundred and forty-six specimens were obtained in this way, ranging in number from only 2 or 3 to 149 per family. The mean spine number of the families ranged from 10.40 to 14.07. Variations in spine number occurred among the descendants of

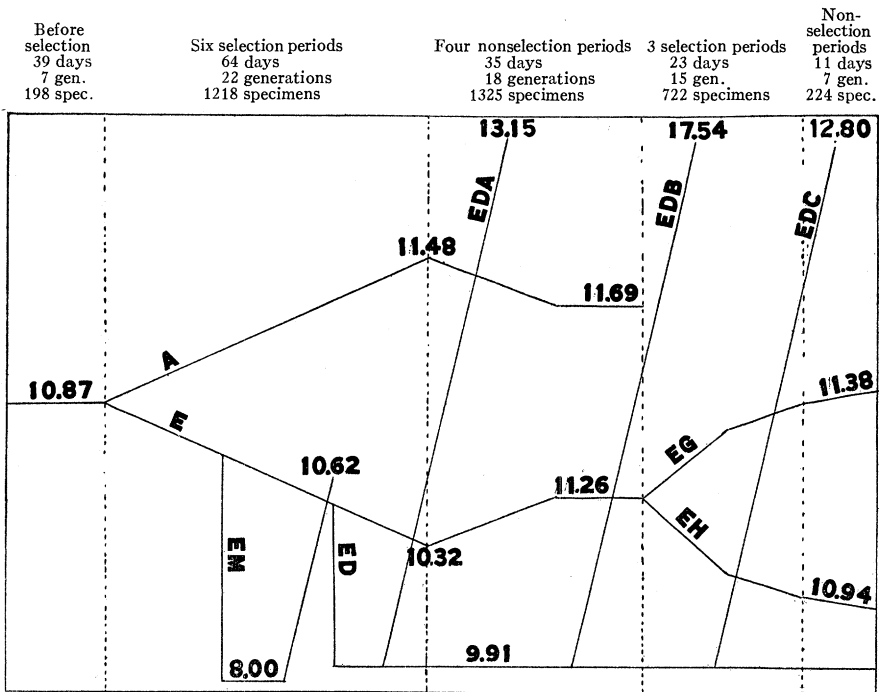


FIG. 2. DIAGRAM SHOWING THE MOST IMPORTANT HERITABLY DIVERSE LINES DERIVED FROM A SINGLE SPECIMEN OF *ARCELLA DENTATA* (NO. 58) BY FISSION

The character used was spine number. The letters indicate the designation of the lines, and the numbers are the mean spine numbers.

single specimens during fission and these variations were in part inherited. It was found that the hereditary constitution of the different families was different with respect to spine number and the conclusion was reached that a 'wild' population consists of a large number of heritably diverse families so far as spine number is concerned, and also probably as regards diameter, since spine number and diameter are closely correlated.

The main problem was next undertaken, i.e., an attempt was made to isolate heritably diverse lines from among the descendants of a single specimen produced

by vegetative reproduction. A specimen, numbered 58 (fig. 1, *A*) was chosen for this work because it was near the mean of the species in diameter and spine number, and multiplied rapidly. Figure 2 shows the principal results of the experiments. During the thirty-nine days before selection was begun 198 specimens were obtained from number 58, representing 7 generations. These varied in spine number from 8 to 13, with a mean of 10.87. Selection was then inaugurated and carried on for six periods totalling sixty-four days. During this time 1192 specimens were reared, belonging to 22 generations. The work was divided into periods so that any changes due to environmental conditions would be revealed, and also because one investigator can take care of only a few hundred specimens at one time, and when the limit has been reached a new selection has to be made. At first all parents and progeny were kept until the end of each selection period, but later selection was also practiced during the periods. An effort was made to obtain a line (*A*) with a high mean spine number and another line (*E*) with a low mean spine number. Specimens within the high line that possessed 12 or more spines were selected and those within the low line with 10 or less. Past performance was used as the basis of selection, i.e., specimens in the high line that had a high spine number and had near relatives with a high spine number were chosen, and similarly specimens in the low line that had a low spine number and had near relatives with a low spine number were chosen for continuing the lines. During the six selection periods the differences between the mean spine numbers of the two lines were as follows: -0.07, 0.50, 0.40, 0.48, 0.84, and 1.16, and the mean difference was 0.55. The coefficients of correlation between parents and progeny with respect to spine number during these periods were  $0.060 \pm 0.076$ ,  $0.220 \pm 0.039$ ,  $0.186 \pm 0.042$ ,  $0.185 \pm 0.040$ ,  $0.403 \pm 0.044$ , and  $0.512 \pm 0.039$ .

Selection was then stopped and during four periods totalling thirty-five days, no selection was practiced. As many specimens as could be taken care of were kept during this time and as soon as one divided the 'parent' was eliminated and the offspring kept. In this way 1325 specimens were obtained belonging to 18 generations. At first regression occurred in both lines but later the mean difference between them remained almost constant. These differences for the four periods were 0.94, 0.07, 0.41, and 0.43, and the mean difference was 0.46. The decrease in the difference after selection was stopped was probably due to the production and inclusion within the high line of low spined specimens that would have been eliminated during the selection periods and within the low line of high spined specimens that likewise would have been eliminated. Each line, however, should give rise to as many high as low spined specimens, and hence the means of each would not vary after an equilibrium had been reached and the difference between them would be permanent. The coefficients of correlation between parents and progeny within the high line during these four periods was  $0.170 \pm 0.027$  and within the low line  $0.197 \pm 0.024$ .

The low line (*E*) was then subjected to selection in a similar way and a high

line (*EG*) and a low line (*EH*) were obtained during three selection periods of twenty-three days during which 722 specimens were produced belonging to 15 generations. The average difference between the mean spine numbers of the two lines during these three selection periods was 0.30. These selection periods were then followed by a nonselection period of 11 days during which 224 specimens were obtained belonging to 7 generations. The difference between the means of the two lines during this nonselection period was 0.44. It was concluded from these studies that two lines heritably diverse with respect to spine number, had been isolated from among the descendants of the low line (*E*).

Measurements were made during part of the nonselection periods to determine whether or not the diversities in spine number in lines *A* and *E* were accompanied by similar diversities in diameter. One hundred and twenty-seven specimens from the high line gave a mean diameter of 27.26 units of 4.3 microns each and 136 from the low line a mean diameter of 26.92 units. The difference of 0.34 unit shows that the two lines were different in diameter as well as in spine number, and that on the average the greater the diameter the more numerous are the spines. A marked correlation was found between the diameters of the parents and those of their progeny, the coefficient of correlation being  $0.489 \pm 0.035$ . A high correlation also existed between spine number and diameter, the coefficient of correlation being  $0.255 \pm 0.042$ .

Measurements were also made of the diameters of 384 of the progeny of the two branches (*EG* and *EH*) of the low line (*E*). These showed a mean difference in diameter of 0.26 unit corresponding to the difference in spine number.

These data prove that the descendants of a single specimen of *Arcella dentata* produced by vegetative reproduction differ slightly from one another in their hereditary constitution (fig. 1, *B* and *C*) and that heritably diverse lines may be isolated from among them, differing both in spine number and in diameter, and that these two characters are closely correlated. These heritably diverse lines resemble certain of the families that were reared from 'wild' specimens, and suggest that differences in the hereditary constitution of these wild specimens may have originated in the same way.

During the course of this investigation several branches were studied that arose from what seemed to be "mutations." These are indicated in figure 2 by the lines *EM*, *ED*, *EDA*, *EDB*, and *EDC*. These all appeared in the low line. Specimen *EM* had 8 spines and was only 18 units in diameter (fig. 1, *D*). Its parent had 10 spines and was 27 units in diameter. A large number of descendants (403) were reared from this small specimen, but it was found that the small diameter and lesser number of spines did not persist, but that the progeny of the fourth generation had regained the diameter and spine number of the low line from which *EM* was derived. The origin of this small specimen was therefore probably due to environmental conditions. Studies of this and certain other small specimens seem to show that it takes three or four generations for the progeny of a very small specimen to regain the normal diameter and spine number of the parental line.

The line derived from specimen *ED* is of special interest, since within it appeared the greatest diversities that were found during the entire investigation. The progeny of *ED* had a mean spine number of 9.91 and a mean diameter of 23.51 units (fig. 1, *E*). At the same time the mean spine number of the parent line (*E*) was 10.99 and the mean diameter was 27.05 units, giving a difference in mean spine number of 1.08 and in mean diameter of 3.54 units. Furthermore the differences persisted for many generations and until the line was discontinued. Specimen *ED* therefore fulfilled the conditions usually required of a mutation, i.e., it was a sudden large variation that was inherited.

From line *ED* there were derived three branches, *EDA*, *EDB* and *EDC*, that quickly exceeded in diameter and spine number any other branches in the entire family 58. The largest specimen appeared in branches *EDB*. It had 20 spines and a diameter of 40 units (fig. 1, *F*). These branches, however, soon died out for some unknown reason, although they were cultivated as carefully as possible.

The general conclusion reached is that within a large family of *Arcella dentata* produced by vegetative reproduction from a single specimen, there are many heritably diverse branches. These diversities are due both to very slight variations and to sudden large variations ('mutations'). The formation of such hereditarily diverse branches appears to be a true case of evolution that has been observed in the laboratory and that occurs in a similar way in nature.

<sup>1</sup> Middleton, A. R. J. Exp. Zool., **19**, 1915. (451-503.)

<sup>2</sup> Jennings, H. S. Genetics, **1**, 1916, (407-534.)

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## THE IMPORTANCE OF NIVATION AS AN EROSION FACTOR, AND OF SOIL FLOW AS A TRANSPORTING AGENCY, IN NORTHERN GREENLAND

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Nivation and solifluction, two closely related and important physiographic processes of Arctic lands, are perhaps nowhere better illustrated than in those coastal areas of northern Greenland not covered by the permanent ice-cap. The climate and the topography are favorable to the high development of these processes; the rather heavy snowfall that melts gradually during the short summer promotes the work of nivation; and the high relief, with numerous small plateaus and generally steep slopes, affords opportunity for the action of solifluction. The presence of an 'ice-table' everywhere, not deep below the surface, is an added favorable condition. As a consequence